THE NICKEL BULLETIN

A MONTHLY SUMMARY OF CURRENT INFORMATION

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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

NON-FERROUS ALLOYS

Nickel-Titanium Alloys: Equilibrium Diagram

D. M. POOLE and W. HUME-ROTHERY: 'The Equilibrium Diagram of the System Nickel-Titanium.'
Jnl. Inst. Metals, 1954–55, vol. 83, July, pp. 473–80; Advance Copy 1623.

The equilibrium diagram of the complete nickel-titanium system was investigated above 900°C., using thermal, microscopical and X-ray methods.

The addition of titanium to nickel produces a marked depression of the liquidus and solidus curves, which sink to a eutectic at 1304°C., the solid phases being the solid solution in nickel and the phase Ni_3Ti. The latter is of almost fixed composition and gives rise to a pronounced maximum on the liquidus at 1380°C. The solid solution in nickel remains supersaturated even after long times of annealing at 1000°C., and it is probable that the true equilibrium curve was not obtained. At 1118°C., there is a eutectic of Ni_3Ti and a phase of slightly variable composition based on the equiatomic ratio NiTi, which gives rise to a maximum on the liquidus curve at 1310°C. The liquidus then falls to 984°C., at which temperature the phase $NiTi_2$, of almost fixed composition, is formed by a peritectic reaction. At 942°C. there is a eutectic horizontal of $NiTi_2$ and the solid solution of nickel in β-titanium: above this both solidus and liquidus rise steeply to the melting point of titanium, which is estimated as 1680°C. Some lattice-spacing data are included.

The authors findings are discussed in relation to previous work which has been concerned with the comparable region of temperature.

Creep Characteristics of (Nickel)-Aluminium Bronze Alloys

J. P. DENNISON: 'Creep Behaviour at 300°C. of a Group of Precipitation-Hardening Alloys based on the Alpha Copper-Aluminium Phase.'
Jnl. Inst. Metals, 1954–55, vol. 83, July, pp. 465–71; Advance Copy 1622.

In a previous paper (*ibid.*, 1953–54, vol. 82, p. 117) the author reported a study of the creep behaviour of selected precipitation-hardening alloys based on the α copper-aluminium phase. In that work all the tests were made at 450°C., a temperature at which precipitation proceeded at an appreciable rate during reheating. The present paper is concerned with the creep characteristics of some of the same alloys at 300°C., at which temperature there was neither change in hardness nor visible precipitation during reheating periods up to 1,000 hours.

Specimens in the solution-treated, slowly cooled and aged conditions were subjected to creep, creep-rupture and short-time tensile tests at 300°C., and, in addition to the information on the creep and short-term mechanical properties of the alloys, a detailed report is made of the structures characteristic of the respective conditions, demonstrating inter-relationship of structure and high-temperature behaviour.

The alloys examined are shown in the table below.

The alloys which contained cobalt, iron and nickel, which at normal ageing temperatures exhibited a form of discontinuous precipitation at the grain

Nominal Composition		Actual Composition		
Al %	Alloying Element %	Cu %	Al %	Alloying Element %
7	1·5 Co	91·58	6·85	1·54 Co
7	1·0 Co, 1·0 Fe	91·23	6·71	1·09 Co, 0·96 Fe
7	1·6 Co, 5 Ni	86·41	6·88	1·72 Co, 4·97 Ni
6	1·5 Fe	92·30	6·16	1·52 Fe
6	0·75 Ti	92·95	6·23	0·73 Ti
7	0·6 Zr	92·51	6·86	0·60 Zr

boundaries, showed strain-induced boundary precipitation during test. In such cases reduction in creep ductility resulted, and was generally associated with internal cracking. For these alloys the slowly cooled state gave the best combination of properties.

Alloys containing titanium or zirconium showed high ductility at all rates of strain.

The principal effects of precipitation before test were to reduce the period and extent of transient creep, and to favour development of fracture.

Condenser-Tube Alloys: Factors Affecting Selection

See abstract on p. 139.

Spray-Metallized Coatings: Technique and Applications

See abstract on p. 138.

CAST IRON

High-Temperature Properties of Plain and Alloy Cast Irons

J. R. KATTUS: 'Properties of Cast Iron at Elevated Temperatures.' *Foundry*, 1955, vol. 83, Feb., pp. 96–7, 230–2, 234, 237.

This article comprises a progress report on work being carried out under the aegis of the Joint A.S.T.M.-A.S.M.E. Committee on the Effects of Temperature on the Properties of Metals. The main purpose of the work is to establish fundamental data on the characteristics, in the range 700°–1000°F. (370°–540°C.), of cast irons of the types covered by A.S.T.M. specification A 278, classes 40, 50 and 60 (grey iron castings having, respectively, minimum tensile strengths of 40,000, 50,000 and 60,000 p.s.i.: 18, 22 and 27 tons per sq. in.).

The programme covers (1) a survey of the literature, (2) screening tests on a large number of samples, with creep and stress-rupture tests on selected irons, with a view to ascertaining the types showing most promise for high-temperature service, and (3) thermal-shock tests on irons which have shown good creep and stress-rupture properties.

The present article summarizes the literature and gives the results of preliminary screening tests. The conclusions drawn from published information (to which reference is given in a *bibliography* of 27 items) are as follows:—

'The information from the literature survey shows only a partial correlation between creep properties and other high-temperature properties. For example, small chromium additions appreciably increase resistance to growth, thermal shock, and deterioration of tensile properties at high temperatures, whereas molybdenum is not very effective in these respects. Molybdenum is, however, much more effective in improving creep-resistance than chromium, and is, apparently, the most effective alloying element for improving stress-rupture properties. Austenitic irons with nickel contents in the range from 14 to 25 per cent. are reported to perform well in all elevated-temperature tests. This result is to be expected, since austenitic structures are known to enhance the heat-resistance of steels. An exception is the high-silicon austenitic irons, which show poor creep-resistance. High-silicon ferritic irons, however, are resistant to both growth and creep. At 1200°F. (648°C.) graphitizing pre-anneal shows promise of producing the same effect as high silicon content. Alloying copper with cast iron seems to have no beneficial effect on any elevated-temperature properties. Small nickel additions are not very beneficial. High chromium content (16–33 per cent.) in cast iron has been reported to improve shock- and growth-resistance greatly. Chromium additions of this magnitude are probably not practical, however, because of their embrittling effects.

'The information in the literature indicates that alloy additions of chromium, molybdenum and nickel (14 per cent. or more) show the most promise for producing good creep, stress-rupture and thermal-shock properties in cast iron. Since vanadium, titanium, and tungsten are beneficial to the creep properties of steel, they probably merit some investigation in cast iron. A graphitizing pre-anneal is a possible technique for improving heat-resistance.

'These conclusions are based on very limited information. Many more experimental data are required in order to draw definite conclusions concerning the merits of various cast irons for high-temperature service.'

For the second phase of the investigation, the preliminary screening tests consisted of hardness determinations on selected irons after holding for various periods at 1100° and 1200°F. (593° and 648°C.). All the specimens were stress-relieved for two hours at 950°F. (510°C.) before test. The types of cast iron used are shown in the table on the next page.

The *ascending* order of merit, as gauged by resistance to softening, is as follows:—

Iron 3, 4, 6, 12 (unalloyed).
„ 1 (molybdenum-containing).
„ 8 (ferritic nodular, unalloyed).
„ 9 (pearlitic nodular, unalloyed).
„ 5 (nickel-molybdenum alloy cast iron).
„ 2 (chromium-nickel alloy cast iron).
„ 7 (chromium cast iron).
„ 10 and 11 (cast iron alloyed with chromium, nickel, molybdenum and vanadium).

The following general conclusions are drawn from these tests.

'The results show good correlation between resistance to softening at elevated temperatures and alloy content of the various cast irons. Unalloyed irons showed the poorest resistance to softening, and the most highly alloyed irons (chromium, nickel, molybdenum, vanadium) were the most resistant. Chromium

Iron No.	C %	Si %	Mn %	P %	S %	Cr(1) %	Ni(1) %	Mo(1) %	Cu(1) %	Mg(1) %	V(1) %
1	3·21	1·74	0·91	0·19	0·11	0·04	0·10	0·33	0·13	—	—
2	3·22	1·82	0·90	0·12	0·09	0·20	0·33	0·04	0·31	—	—
3	3·20	1·86	0·86	0·12	0·12	0·14	0·18	0·03	0·16	—	—
4	3·07	1·98	0·81	0·10	0·11	0·10	0·19	0·05	0·22	—	—
5	2·98	1·81	0·79	0·06	0·10	0·05	1·41	0·47	0·24	—	—
6	3·19	2·08	0·58	—	0·12	0·09	0·05	0·03	0·17	—	—
7	3·22	2·11	0·69	0·10	0·09	0·52	0·05	0·03	0·29	—	—
8	3·45	2·86	0·21	0·02	0·01	0·02	0·01	0·05	0·03	0·07	0·04
9	3·45	2·86	0·21	0·02	0·01	0·02	0·01	0·04	0·03	0·07	0·04
10	3·03	1·80	—	—	—	0·35	1·12	0·38	0·09	0·01	0·10
11	3·02	1·94	0·72	0·10	0·09	0·27	1·28	0·50	0·08	0·01	0·11
12	3·21	1·48	0·88	0·05	0·09	0·10	0·10	0·01	0·18	0·01	0·01

(1) Spectrographic analyses

is the most effective single alloying element for preventing softening. Molybdenum has very little effect, but an addition of nickel+molybdenum is slightly better. Unalloyed nodular iron resists softening to a slightly greater degree than unalloyed grey iron.

'Irons with ferritic matrices are, of course, softer than those with pearlitic matrices, in the as-cast or heat-treated conditions. During annealing at 1100° or 1200°F. (593° or 648°C.) for extended periods of time, however, the ferritic irons do not lose as much hardness as those with pearlitic matrices. The final hardness is, apparently, more dependent upon alloy content than upon the amount of ferrite and pearlite in the original structure. The presence of martensite in the starting structure seems to contribute somewhat to the retention of hardness after annealing at 1100° and 1200°F. (593° and 648°C.). In general, the type of alloy additions has a greater effect upon final hardness than graphite or matrix structure.

'The literature survey indicated that resistance to creep and stress-rupture cannot be predicted confidently on the basis of other elevated-temperature tests. It would not be wise, therefore, to assume that irons with the most resistance to softening have the best creep and stress-rupture properties. Molybdenum cast irons, for example, did not resist softening nearly as well as those containing chromium. Previous creep testing, however, indicates that the molybdenum irons are superior in creep and stress-rupture properties.'

Effect of Low Temperatures on Brittleness in Metallic Materials

See abstracts on pp. 128–130.

CONSTRUCTIONAL STEELS

Effect of Low Temperatures on Brittleness in Metallic Materials

AMER. SOC. TESTING MATERIALS: 'Symposium on Effect of Temperature on the Brittle Behaviour of Metals, with particular reference to Low Temperatures.' *A.S.T.M. Special Tech. Publn. No.* 158, 1954; 474 pp.

The volume contains the papers and discussion presented at the symposium held during the Annual Meetings of the Society in June 1953.

The contributions made covered many aspects of the subject, including theoretical analysis of the mechanism of brittle fracture, the influence of design factors on brittleness, the effect of metallurgical variables (composition, structure, heat-treatment, etc.), and methods of test for assessment of brittleness and toughness. In all the discussions, the influence of low temperature, *per se*, was given special prominence.

Much of the material in these groups, although not relating specifically to nickel-containing materials, is directly or indirectly applicable to them, and in some of the papers reference is made to work on nickel-containing steels and cast irons. Notes on papers falling into the latter category are given below:

C. H. LORIG: 'Metallurgical Aspects of Low-Temperature Behaviour in Ferrous Materials', pp. 147–62; disc. p. 163.

This paper includes discussion of the following factors, as influencing brittle or tough behaviour: *atomic structure* (including (*a*) reference to the general freedom of the austenitic chromium-nickel steels

from brittle sensitivity, and (*b*) conditions in which brittleness may be induced); *tensile ductility; compositional effects* (including summary of data on the effects of the individual elements carbon, manganese, oxygen, aluminium, and various alloying metals). Attention is directed to the fact that 'nickel is generally accepted as being beneficial to low-temperature toughness, especially when the carbon content of the steel is kept low.' Specific findings on this subject are quoted. Reference is made to limitations in the amount of nickel which, from the point of view of low-temperature toughness, can usefully be present in the more-highly-alloyed ferritic steels. Heat-treatment, as a factor affecting retention of toughness, is also reviewed, including some consideration of temper-brittleness in nickel-alloy and other steels, and strain-ageing.

J. A. RINEBOLT: 'Effect of Metallurgical Structures on the Impact Properties of Steels', pp. 203–14; disc. p. 215.

Comparison is made of the impact properties of spheroidite produced from martensite, of spheroidite produced from pearlite, and of a normalized structure: Charpy V-notch properties were used as criterion. Five series of steels were used: carbon was varied in the first, manganese in the second, silicon in the third, phosphorus in the fourth, and nickel in the fifth.

The spheroidite produced from martensite showed the highest maximum-energy value, and a low transition temperature; that produced from pearlite had the highest transition temperature. The normalized structure showed the lowest maximum-energy value, but the transition temperature of the normalized steel of basis type (carbon 0·30, manganese 1·0, silicon 0·30, per cent.) was about the same as that of the spheroidite produced from martensite.

The transition temperature for steels of all three structures was lowered by the addition of manganese or of nickel, but raised by increasing carbon, phosphorus, or silicon. (The nickel range studied was 0·04–1·80 per cent).

C. R. MAYNE, V. N. KRIVOBOK and C. W. MUHLENBRUCH: 'Tension-Impact Strength and Strain Distribution, at Room and Sub-Zero Temperatures, of Stainless and other Steels', pp. 382–400; disc., pp. 401–4.

It is pointed out that the austenitic stainless steels offer a combination of mechanical properties which renders them eminently suitable for many structural applications, and that these properties are not adversely affected by sub-zero temperatures. A considerable amount of data, culled from Charpy and Izod impact tests, is already available to confirm the toughness characteristic of these steels at low temperatures. There is, however, a relative dearth of information on tension-impact properties, and the work now reported was planned to fill this gap.

A study was made of the behaviour of stainless-steel sheet samples under conditions of impact loading. Variables selected for investigation were (*a*) composition of the steel, (*b*) 'temper', i.e., tensile properties, (*c*) temperature, and (*d*) gauge length and/or the effect of notches. The materials used were annealed and half-hard straight 17-7 chromium-nickel steel, annealed and half-hard steels containing chromium about 18, nickel about 9, per cent., 17-7 precipitation-hardening steel in the hardened condition, two low-alloy steels (nickel-chromium-copper and nickel-copper types), and a carbon steel.

Four types of tension-impact specimen were used, of which the designs are shown in the paper, and means were adopted to permit (*a*) evaluation of plastic deformation (elongation) accompanying fracture, and (*b*) study of distribution of elongation over and beyond the gauge length. Experimental results are reported at considerable length, and it is emphasized that they are condensed from even more extensive data.

From the results obtained, the authors deduce that sufficient evidence is available to indicate that the degree of toughness of steels should not be judged solely by numerical results expressed in ft.-lb. The ability of a steel of given tensile strength and elongation to *absorb dynamic energy before fracturing* is determined by several factors, among which the following should be considered:—

(*a*) volume of material (under gauge length in the case of laboratory testing), (*b*) deformation characteristics, and (*c*) tensile strength, as such. The energy-absorption capacity is, obviously, altered by such external factors as temperature and rate of application of stress. The tests reveal that both the total energy and energy per unit volume for stainless steels is markedly higher at −40°F. (−40°C.) than at room temperature: with the two low-alloy steels the effect of lowering to that temperature is negligible, and with the carbon steel the effect is adverse.

Earlier work, by one of the present authors and by others, has shown that the static tensile strength of annealed stainless steels increases rapidly as the temperature is lowered to sub-zero values, and that this increase is accompanied by only slight loss in ductility. Tension-impact tests reported in the present paper show that the same statements apply in the dynamic testing of annealed chromium-nickel steel. It has been demonstrated earlier that cold-rolled austenitic stainless steels show less increase in tensile strength as the temperature is lowered but that there is definite change in the pattern of elongation. In tests at both room and sub-zero temperatures elongation at fracture or close to it is about the same, but at sub-zero temperatures elongation away from the fracture is considerably higher. Again, similar observations were made in dynamic tension-impact testing: this is illustrated in the paper by reference to the half-hard 18-9 chromium-nickel steel.

J. S. VANICK: 'Low-Temperature Toughness of Flake- and Spheroidal-Graphite Cast Iron', pp. 405–14.

Until recent years low-temperature applications for cast iron have been in a region not lower than about −50°F. (−45°C.), but development of other

uses, involving lower temperatures, has made imperative the accumulation of additional data, for the range −100° to −300°F. (−73° to −184°C.). This paper records determinations of tensile strength, impact strength and hardness, at −108° and −320°F. (−77° and −195°C.), on a range of cast irons representative of unalloyed pearlitic, nickel-containing pearlitic, nickel-alloy acicular, austenitic-martensitic, and austenitic types, spheroidal-graphite irons, and irons subjected to various tempering treatments.

The results give the following indications of the influence of sub-zero temperatures on the respective classes of cast iron:—

In pearlitic irons cooled to −100°F. (−73°C.) there is a fall of about 10–20 per cent. in impact strength and the decrease is of the order of about 50 per cent. when the same irons are cooled to −300°F. (−184°C.). Acicular nickel-molybdenum cast irons show a similar percentage change, but as the room-temperature impact toughness of these materials is about double that of the pearlitic irons they retain at −300°F. (−184°C.) a degree of toughness equal to that of the pearlitic irons at room temperature. The nickel-molybdenum cast irons do not appear to undergo a phase change within the range room temperature to −100°F. (−73°C.), but there is a pronounced transition on cooling to −300°F. (−184°C.). When these irons are tempered for 5 hours at a temperature above 900°F. (482°C.), however, no further change takes place at sub-zero temperature, and they are therefore suitable, from the point of view of impact strength, to be used at −300°F. (−184°C.) for applications for which the pearlitic irons would be used at room temperature.

The austenitic, higher-nickel cast irons show a better toughness than the pearlitic irons at room temperature and retain a greater percentage of it at temperatures down to −300°F. (−184°C.). The presence of not less than 25 per cent. of nickel effectively stabilized irons of the Ni-Resist type, but those containing less than that amount of nickel showed some evidence of instability on cooling to −300°F. (−184°C.).

At room temperature the spheroidal-graphite irons, as a class, show much higher impact properties than flake-graphite irons, and they retain a higher toughness at temperatures down to −100°F. (−73°C.). Low-phosphorus, low-manganese types are to be preferred. At −300°F. (−184°C.) the toughness of the spheroidal-graphite irons was equal to, but not higher than, that of the flake-graphite irons. The best impact values recorded were obtained from spheroidal-graphite modified Type 2 Ni-Resist, containing 24 per cent. of nickel and no chromium. This material could not be broken within the capacity of the Izod machine, even when subjected to four repeated blows at −300°F. (−184°C.).

G. N. J. GILBERT: 'Ductile and Brittle Failure in Ferritic Nodular Irons (Nickel-Magnesium Type)', pp. 415-31.

(See abstract in *Nickel Bulletin*, 1955, vol. 28, No. 4, p. 66).

G. N. J. GILBERT: 'The Low-Temperature Properties of Cast Irons', pp. 432-55.

This paper reports a systematic series of tests on flake-graphite cast irons of pearlitic, acicular (nickel-molybdenum), martensitic (nickel) and austenitic (high-nickel-copper) types, and on spheroidal-graphite irons. Full details of composition of the irons representative of each type are given.

Impact and tensile properties were examined at temperatures down to about −180°F. (−117°C.) and phase changes were studied by dilatometric methods. Extensive experimental data are reported for the individual materials. The general conclusions drawn from the tests are summarized below:—

Pearlitic flake-graphite cast iron show gradual fall in impact value and rise in tensile strength as the temperature is lowered. At −150°F. (−101°C.) impact fell by amounts up to 30 per cent., and the increase in tensile strength amounted, in some cases, to 15 per cent. Percentage fall in impact at −150°F. (−101°C.) was usually less in irons of high phosphorus content and in those having poor graphite structures and showing low impact at room temperature.

Tests at elevated and at sub-zero temperatures, on a series of irons of increasing phosphorus content, showed that a change comparable with the ductile-to-brittle change in steels occurs in flake-graphite cast irons. The range of temperature over which the transition occurred was wide, and rose with increase in phosphorus content.

Acicular irons showed a fall of up to 50 per cent. in impact at −150°F. (−101°C.) and the tensile strength rose by about 18 per cent. A sudden decrease occurred at the phase change. (A series of acicular irons transformed at temperatures between −54° and −83°F: −47° and −64°C.) Irons of this type which had been transformed at low temperatures and tested at room temperature showed lower impact than those tested at the low temperatures, indicating that the transformed material suffered a fall in impact strength with rise in temperature. Tests at high and at low temperatures showed a maximum in the impact/temperature curve at about room temperature: the peak was higher in an as-cast iron than in an iron heat-treated at 626°F. (330°C.) for six hours. The structure of austenitic cast irons in which some of the nickel had been replaced by about 7 per cent. of copper changed from austenite to martensite at low temperatures, and a similar change was detected in a nickel-manganese austenitic iron. Temperature of transformation in austenitic irons varied with composition; it fell as the silicon and phosphorus contents were reduced and as the manganese, chromium, nickel and copper contents were increased. It is considered likely that an austenitic cast iron containing not less than 13 per cent. of nickel and 6·5 per cent. of copper will not transform above −240°F. (−151°C.) if the silicon is below 1·8, the chromium above 1·7 and the manganese above 1 per cent.

The impact properties of the austenitic cast irons rose at low temperatures, and in the nickel-copper grades reached a maximum on approaching the

temperature of the phase change. Increases of 50 and 75 per cent. in impact were found in cast irons which transformed at −58°F. (−50°C.) and −126°F. (−87°C.), respectively. In a nickel-manganese austenitic iron the maximum occurred well above the transformation temperature. Below the transformation temperature impact values fell. The room-temperature impact strength of austenitic cast irons which had been soaked at temperatures below those at which transformation occurred was lower than that of the same specimens tested at low temperatures, showing that even in partially transformed irons impact increased with fall in temperature.

Both as-cast pearlitic and annealed ferritic spheroidal-graphite irons showed a transition from ductile to brittle behaviour in impact; the change occurred at higher temperatures for the as-cast than for the ferritic irons, and the transition temperature fell as the percentage of ferrite in the structure increased. In the ductile range impact values increased with increase in percentage of ferrite. In both V-notched and un-notched specimens which had been treated to the completely ferritic condition the transition temperature, ductile to brittle, rose with increasing silicon and phosphorus. S.G. irons likely to be subject to impact conditions in service should therefore have the lowest possible silicon and phosphorus content compatible with attainment of other requirements.

R. W. KRAFT: 'The Impact Properties of Ferritic Ductile Iron', pp. 456–72; disc. pp. 472–4.

The main object of the work reported was to evaluate the influence of composition and structure on impact properties of S.G. iron in the ferritic condition, as covered by A.S.T.M. Tentative Specification grade 60–45–10, which provides for the following minimum properties:—

	p.s.i.	t.s.i.
Tensile strength	60,000	27
Yield strength, 0·2% offset	45,000	20
Elongation	10%	

The tests were made on a modified A.S.T.M. 'Y' specimen, on cupola and induction-furnace melted S.G. irons representing a composition range of silicon 1·8–3·9, phosphorus 0·02–0·08 per cent. All the irons were annealed at 1650°F. (900°C.) for a minimum of four hours, followed by slow cooling, with an arrest at 1300°F. (705°C.) for four hours.

Impact strength and appearance of fracture were studied in specimens broken at temperatures of −100° to +212°F. (−73° to +100°C.).

The tests revealed no sharp transition temperature. As the temperature was lowered down to −100°F. (−73°C.), or the silicon or phosphorus content was increased, impact fell, but only slowly, and the transition from tough to brittle fracture was gradual.

The maximum silicon content permitting a ductile fracture in a low-phosphorus S.G. iron at room temperature is 2·4 per cent., but completely brittle fracture does not occur at that temperature until silicon is increased to about 3·0 per cent. The author gives also other silicon/phosphorus/temperature relationships, as affecting ductile or brittle fracture.

The results indicate that nickel has no effect on impact strength, but this element can be usefully employed to strengthen the ferrite in a low-silicon S.G. iron, to make possible compliance with the tensile requirement, without causing a fall in impact strength.

Titanium in Iron and Steel: Textbook

G. F. COMSTOCK: 'Titanium in Iron and Steel.' Published, for the Engineering Foundation, by *John Wiley and Sons, Inc., New York; Chapman and Hall, Ltd., London;* 1955; xii + 294 pp. Price 48/-.

This most recent addition to the 'Alloys of Iron', series of monographs has been prepared by the methods which have been adopted for earlier volumes. The author has had over 40 years of specialized experience of titanium, and his work has been supported by the co-operation of fifteen collaborators whose work has brought them into contact with the study and/or use of titanium-containing materials.

The book comprises a correlation and critical review of all important data in world literature on titanium in cast iron and steels: references to original sources constitute a *bibliography* of nearly 300 items.

The introductory chapter is devoted to a consideration of the minerals in which titanium is found, the treatment of titanium-bearing ores, the preparation, extraction and properties of the metal, and the treatment and properties of iron-titanium alloys. This leads to a detailed examination of the use of titanium as a deoxidizer in rimmed and killed wrought steels, its effects on nitrogen and sulphur in steel, the particular uses of the element in cast steels, and the effects of titanium when present in cast iron of various types.

The last five chapters are concerned with the effects of titanium in individual types of steel: its influence when present as the sole alloying element in unalloyed pearlitic steels, or in simple and complex low-alloy steels; carbide stabilization by titanium (in unalloyed steels or in steels of medium or high alloy content), and the uses of titanium in precipitation-hardening steels and in complex heat-resisting alloys.

Like the other members of the 'Alloys of Iron' series, the titanium volume is to be welcomed as providing, within its specified field, the most comprehensive summary of information yet available.

Spectrochemical Control Analysis in Steelworks

G. HARTLEIF and H. KORNFELD: 'Introduction of Spectrochemical Methods of Rapid Control Analysis in Steelworks.' *Stahl und Eisen*, 1955, vol. 175, May 5, pp. 587–90.

The paper gives full details of technique which has been standardized in a large steelworks for control

in production of plain and low-alloy steels. By the method described, it is possible, in one operation, to determine silicon, manganese, chromium, nickel, copper, molybdenum, vanadium and aluminium, with a degree of accuracy adequate for routine control. The paper includes recommendations with regard to preparation of the samples, and the precision of the results obtainable is demonstrated by analyses of three samples, in comparison with check analyses made by wet chemical methods.

Creep-Resisting Steels Used in Steam-Power Plants

H. W. KIRKBY: 'The Use of Creep-Resisting Steels in Steam Power Plants.' *Metallurgia*, 1955, vol. 51, Apr., pp. 165–70.

In several new British power stations now under construction the steam turbines have been designed to operate at 1050°F. (565°C.) steam temperature and 1500 lb. per sq. in. pressure. Selection of steels for the main steam piping in these plants is a major consideration, in that at the temperature involved the relative merits of ferritic and austenitic steels must be carefully balanced. In this article the author reviews the properties and discusses the applications of the various types of steel which may be used for (*a*) steam pipes and superheater tubes, (*b*) turbine rotors, (*c*) turbine blades, (*d*) bolts. Service experience and experimental data are assembled to show the relative advantages and limitations of steels which have been employed and/or may be used for these components in future installations.

HEAT- AND CORROSION-RESISTING MATERIALS

Notch-Fatigue Strength of Nickel-Chromium-Cobalt-Iron Alloy at High Temperatures

W. S. HYLER and W. F. SIMMONS: 'Factors Influencing the Notch-Fatigue Strength of N-155 Alloy at Elevated Temperatures.' *Amer. Soc. Mechanical Engineers, Paper No.* 54-A-239, Nov.-Dec., 1954; 28 pp.

Many applications of high-temperature materials involve conditions of repeated loading, necessitating, for design purposes, a knowledge of fatigue as well as of creep characteristics. The present authors briefly note the main work which has been done on this subject, indicating that the current position of knowledge on the effect of notches on elevated-temperature behaviour is inadequate.

The research which they report was initiated with the specific object of studying some of the important factors related to notched behaviour in fatigue. The decision to use N-155 alloy as the test material was based on the following considerations: (1) as a result of work under the auspices of the National Advisory Committee for Aeronautics and others, a substantial amount of information is already available on the static and dynamic un-notched behaviour of this alloy, and (2) material from the same heats which had been used in investigation of other properties was still available for use in notched-fatigue tests. The composition of the alloy is given as carbon 0·13, silicon 0·42, manganese 1·64, chromium 21·22, nickel 19·0, cobalt 19·7, molybdenum 2·90, tungsten 2·61, niobium 0·84, nitrogen 0·13, per cent., iron balance. The material was tested in the precipitation-hardened condition obtained by solution-heating at 2200°F. (1204°C.) for 1 hour, water-quenching, and ageing at 1400°F. (760°C.) for 16 hours.

Three notches, selected to achieve a range in severity, were used, and the other factors investigated were alternating-stress to mean-stress ratio, and temperature (1200° and 1500°F.: 648° and 815°C.). The tests were made on Krouse direct-stress fatigue machines, equipped with hydraulic load maintainers: operation was at about 1,500 cycles per minute. Full details are given of experimental conditions, of the results of each series of tests, of the micro-structural changes in the specimens under test, and of the nature of the fractures obtained.

The authors are of the opinion that, within the range of test conditions used, the observations made justify the following conclusions:—

For low load ratios N-155 is notch-strengthened to some extent in fatigue. The degree of strengthening depends on severity of notch, load ratio, temperature, and time. Greater strengthening appears to be associated with notches of larger radii, with higher temperatures, and with longer times of exposure.

At high load ratios the effect of a notch on the fatigue behaviour of N-155 is detrimental, and this effect is influenced particularly by severity of notch, stress re-distribution (which occurs during the early stages of fatigue), and temperature.

It appears that a rational explanation of notched-bar strengthening in fatigue may be based on geometry of notch, creep or relaxation behaviour, and ductility, but strain-hardening and other metallurgical changes induced by cyclic stress may also be important factors.

Notch-Rupture Strength of High-Temperature Materials

R. L. CARLSON, R. J. MACDONALD and W. F. SIMMONS: 'Factors Influencing the Notch-Rupture Strength of Heat-Resistant Alloys at Elevated Temperatures.' *Amer. Soc. Mechanical Engineers, Paper No.* 54-A-240, Nov.-Dec., 1954; 29 pp.

This paper reports tests made on three typical high-temperature materials, of which the compositions are shown in the table on p. 133.

The main objectives of the investigation were to determine the test conditions in which these materials respond in a brittle manner, i.e., are notch-sensitive, and to study some of the factors which exert an influence on notched and un-notched stress-rupture behaviour. All three alloys were tested in the precipitation-hardened condition. The range of test temperature was 1200°–1600°F. (648°–870°C.).

The most significant conclusions drawn from the detailed investigation made are summarized below:—

Un-notched rupture ductility, although providing

a rough index of available ductility, cannot be used as an efficient guide for indicating notch-sensitivity.

	S-816 %	Waspaloy %	Inconel 'X' Type 550 %
Carbon	0·38	0·08	0·05
Silicon	0·49	0·61	0·28
Manganese ..	1·22	0·80	0·73
Phosphorus ..	0·012	0·017	—
Sulphur	0·018	0·017	0·007
Chromium ..	20·04	18·72	14·97
Nickel	19·43	bal.	bal.
Molybdenum ..	3·98	2·93	—
Tungsten.. ..	3·93	—	—
Niobium ..	2·89	—	1·03(a)
Cobalt	43·32	13·44	—
Iron	3·44	1·17	6·59
Aluminium ..	—	1·29	1·16
Tantalum ..	0·85	—	—
Titanium.. ..	—	2·29	2·5
Copper	—	0·10	0·03

In some cases notch-strengthening was associated in these tests with un-notched rupture ductilities as low as 10 per cent. (e.g., Waspaloy at 1500°F.: 815°C.). In work by other investigators notch-sensitivity has been detected in association with un-notched rupture ductilities as high as 60 per cent.

Notch-rupture ductility appears to be the simplest gauge of notch-sensitivity; notch-sensitivity is associated with notch-rupture ductilities of less than 3 per cent.

The most desirable condition, for design purposes, is for an alloy to be notch-strengthened for a wide range of notch sharpnesses. S-816 was found to fulfil this condition for all the test temperatures used, whereas the Inconel 'X' and Waspaloy alloys satisfy it only at 1600° and 1500°F. (870° and 815°C.), respectively.

It is probable that an alloy which is notch-sensitive for high sharpnesses can be used safely if it can be notch-strengthened for lower notch-sharpness values: this could be achieved primarily by avoiding the use of sharp notches in design. Additional data would be needed for full utilization of this possibility.

A review of the data obtained in this research and of information in the literature indicates that there may be a maximum possible notched-rupture to un-notched-rupture value. For the notch-sharpness values represented in these tests the value appears to be about 1·7, which probably represents the most efficient use of the triaxiality present.

Metallurgical changes which can cause embrittlement must be considered influential in any interpretation of notched and un-notched stress-rupture tests.

The preferred modes of deformation and the type of fracture characteristic of a given alloy are factors of importance: they are considered to be probably responsible for the wide variation in ductility requirements for notch-strengthening of different alloys.

Surface condition, as determined by surface preparation, probably has an influence on stress-rupture results.

The abilities of different alloys to tolerate the presence of cracks initiated during a stress-rupture test can apparently vary markedly. Cracks were frequently observed at the base of unruptured notches in the S-816 alloy, whereas cracks were seldom observed in unruptured notches of the Inconel 'X' or Waspaloy specimens. In these two cases failure evidently occurred shortly after initiation of cracking. Since cracking appears to be initiated during a test, the crack-propagation characteristics of a material are important.

Cast Alloy for Gas-Turbine Blading

D. K. HANINK, F. J. WEBBERE and A. L. BOEGEHOLD: 'Development of a New Gas-Turbine Super Alloy, GMR-235.' *Soc. Automotive Engineers, Preprint* 453, Oct. 12, 1954; 22 pp.

The paper describes the characteristics of a new casting alloy, the composition of which is based on the combined requirement of high-temperature strength, adequate ductility, and low content of strategic materials. The limits established as a practical production specification are shown below:—

Element	%
Carbon	0·10 – 0·20
Silicon	0·60 max.
Manganese	0·25 max.
Chromium	14·00 –17·00
Iron	8·00 –12·00
Molybdenum	4·50 – 6·0
Aluminium	2·50 – 3·50
Titanium	1·50 – 2·50
Boron	0·025– 0·100
Nickel	balance

Particular attention is called to the high level of aluminium+titanium (6·00 per cent. max.) and to the reversed titanium: aluminium ratio (1:1 min.; 2·5:1 max.), in comparison with that used in earlier nickel-base alloys. It is claimed that the relatively high percentages of these elements, coupled with the major effect of boron, on both high-temperature strength and ductility, has resulted in a desirable

combination of properties, even with an iron content as high as 12 per cent. The influence of variation of boron, and of titanium/aluminium content, on properties, is demonstrated.

Study of the effect of various heat-treatments on the properties of GMR-235 has indicated that solution treatment of one hour at 2100°F. (1148°C.), followed by air-cooling or water-quenching, can, in some cases, almost double the stress-rupture life at 1600°F. (870°C.), 28,000 p.s.i. (12·5 tons per sq. in.) stress. Air-cooling is preferred. Annealing for 16 hours at 1800°F. (982°C.) did not improve the properties of solution-treated material, but some advantage was derived from ageing for 5 hours at that temperature from the as-cast condition. The increase in hot strength resulting from the latter treatment, combined with the convenience, in commercial operation, of eliminating a treatment at 2100°F. (1148°C.), would make the 1800°F. (982°C.) ageing a preferred procedure.

In thermal-shock tests, made on the standard N.A.C.A. wedge-type specimen, the specimens were heated by direct flame impingement on the side opposite the wedge tip and were water-quenched selectively at the $\frac{1}{32}$-in. wide tip. Cycling consisted of an 18-minute heating period to 1800°F. (982°C.), followed by a water quench which cooled the tip to room temperature in about 5 seconds. Specimens of this type which were cycled to produce complete crack propagation across the $\frac{1}{32}$-in. edge indicate that the alloy will corrugate or warp, rather than crack in brittle failure.

A limited series of notch stress-rupture tests at various temperatures established that GMR-235 alloy is not notch-sensitive.

Two types of elevated-temperature fatigue testing have been used in evaluating the alloy; the first series under combined static and superimposed dynamic stress, at a frequency of 180 cycles per second, the second under resonant vibratory conditions.

The final section of the paper is concerned with foundry production methods which have been evolved for the new alloy.

With regard to the present position of development, it is stated that over 500 tons of the alloy have been melted and cast into various shapes for gas-turbine service. In flight tests, a control group of 114 engines, representing a larger number of production engines equipped with GMR-235 blades, have accumulated an average of 183 hours service time, and 56 of these have done more than 200 hours of service. No failure has been recorded.

Influence of Composition on Properties of Austenitic Steels at 600°-700°C.

H. A. VOGELS: 'Influence of Various Alloy Elements on the Properties of Heat-Resisting Austenitic Chromium-Nickel Steels in the Range 600°-700°C.' *Stahl und Eisen*, 1955, vol. 75, May 5, pp. 559-70.

The work described in this paper was undertaken with the aim of determining improvements which could be effected in the mechanical properties of austenitic steels in the region which is of interest in steam- and gas-turbine construction. The steels examined (see table below) were in three broad groups:

(1) the 16-13 chromium-nickel niobium-stabilized type, modified by cobalt, 2-20 per cent.;

(2) the same basis type of steel, with additions of molybdenum, with or without vanadium. (In this series the influence of small amounts of nitrogen and of aluminium was also studied);

(3) steels of the 16-13, 15-15, 14-18, 14-12 and 20-20 chromium-nickel types, containing low, medium, and high cobalt, in association with molybdenum, with or without vanadium and/or tungsten.

For details, see table on p. 135.

Extensive tests were made to determine hot-working characteristics, creep strength, susceptibility to embrittlement during high-temperature service, oxidation- and scaling-resistance, and weldability. The results are reported in considerable detail, with good illustrations. All the tests were made with particular reference to the serviceability of the steel within the 600°-700°C. range.

An outline of the main conclusions to be drawn from the results is given below:

The hot-working tests confirmed that production practice, particularly deoxidation, has an important influence on hot ductility. They demonstrate that cobalt, (in the upper ranges studied), high nickel, and the presence of carbide-forming elements such as molybdenum, vanadium and tungsten, may accentuate hot-working problems.

Addition of cobalt in amounts up to 20 per cent. caused only slight improvement in the creep strength of the 16-13 chromium-nickel steel.

Carbide-forming elements (molybdenum, vanadium, tungsten) had a markedly beneficial influence on the high-temperature mechanical properties of the cobalt-free chromium-nickel steels, and the best combination of properties, especially at temperatures above 650°C., was obtained in the austenitic steels containing these carbide-formers in association with substantial amounts of cobalt.

The embrittlement tests revealed a relation between susceptibility and the contents of carbon and of carbide-forming elements. Cobalt-containing chromium-nickel austenitic steels free from molybdenum, vanadium and tungsten were less susceptible to embrittlement than cobalt-free niobium-stabilized steels of similar chromium and nickel content to which none of the three carbide-forming elements had been added. This difference may have been partially attributable also to differences in carbon and niobium + tantalum contents.

Vanadium has a markedly deleterious influence on the scaling-resistance of austenitic chromium-nickel steels, but in steels in which the vanadium content is relatively low the resistance can be improved by additions of cobalt.

In the welding tests a definite relationship was established between susceptibility to micro-cracking and the hot-working characteristics of the steels.

	C %	Si %	Mn %	Al %	Co %	Cr %	Mo %	Ni %	N %	Ta–Nb %	V %	W %
I	0·09	0·42	1·36	—	—	16·1	—	12·7	—	0·72	—	—
	0·08	0·35	2·45	—	2·1	16·4	—	15·2	—	1·37	—	—
	0·02	0·81	1·39	—	6·5	17·0	—	13·7	—	0·84	—	—
	0·04	0·38	2·75	—	10·4	16·9	—	14·1	—	0·41	—	—
	0·02	0·59	1·40	—	16·0	16·8	—	13·5	—	0·97	—	—
	0·03	0·56	2·36	—	21·1	17·1	—	10·8	—	0·45	—	—
II	0·08	0·61	0·95	—	—	16·3	2·0	13·9	—	0·76	—	—
	0·06	0·64	1·36	—	—	16·4	1·4	13·9	0·075	0·78	0·74	—
	0·19	0·48	0·58	0·16	—	15·5	1·7	16·8	0·065	1·78	0·90	—
III	0·17	0·59	1·53	0·11	2·2	15·7	1·7	16·6	0·060	1·84	—	—
	0·16	0·77	1·55	0·13	2·2	15·9	1·7	16·2	0·062	1·92	0·89	—
	0·06	0·35	1·58	—	2·0	15·6	1·5	14·5	—	0·42	0·81	0·78
	0·04	0·21	1·18	0·04	2·1	14·4	1·7	15·3	0·021	0·34	0·87	0·70
	0·07	0·65	1·38	—	4·0	16·5	1·3	14·0	0·042	1·00	0·79	—
	0·06	0·48	1·36	—	6·1	16·6	1·3	14·0	0·063	0·80	0·77	—
	0·06	0·41	1·40	—	8·5	16·4	1·3	13·9	0·065	0·73	0·77	—
	0·16	1·02	1·02	—	6·8	14·2	4·2	18·6	—	(1)	0·35	—
	0·4	1·56	0·94	—	11·9	13·9	1·7	11·6	—	3·26	—	2·50
	0·17	0·38	2·01	—	20·9	19·7	2·8	20·5	—	1·38	—	2·17

(1) Cu 4·0, Ti 0·79 per cent.

Modified '18-8' Chromium-Nickel Steels for High-Temperature Service

CORNELL AERONAUTICAL LABORATORY: 'Modified 18-8 Stainless for Higher Temperatures.'
Materials and Methods, 1955, vol. 41, May, pp. 117–18.

This brief summary is digested from a report of work done to provide a preliminary assessment of the influence of minor additions of other elements, on high-temperature strength of '18-8' and '18-12-Mo' chromium-nickel steels. The criterion adopted was 100-hour rupture life at 1350° and 1500°F. (732° and 815°C.).

Approximately 150 steels, based on chromium 18-nickel 9 per cent. and chromium 17-nickel 12-molybdenum 2·5 per cent. types, were tested. The additions made were titanium, boron, vanadium and zirconium, used singly, and titanium + boron. The influence of carbon and of nitrogen content was also determined, and some study was made of the influence of temperature of solution treatment (2100°–2300°F. : 1148°–1260°C.).

The following summary is made of the principal findings:—

Additions of titanium, boron, zirconium, vanadium, nitrogen and carbon are all capable of improving the 100-hour rupture strength of these steels at 1500°F. (815°C.). Reasonable ductility is maintained after strengthening by use of the relatively high solution-treatment temperatures mentioned. In general, maximum high-temperature strength increased as the carbon level was raised; the largest increment occurred between 0·07 and 0·15 per cent. carbon. Ductility at rupture was relatively unaffected.

Under given conditions of heat-treatment, and at similar levels of alloy addition, the high-temperature strength of the 17-12-2·5 chromium-nickel-molybdenum steel is superior to that of the 18-9 chromium-nickel type. In the 18-9 steel, solution treated at 2100°F. (1148°C.) similar additions of all the alloy additions conferred the same degree of improvement of high-temperature strength. In the 17-12-2·5 chromium-nickel-molybdenum steel a boron addition gave the most significant increase in rupture strength of any single alloy tested. In steels treated at 2100°F. (1148°C.) combined additions of titanium and boron produced the most marked improvement in high-temperature strength, without sacrifice of ductility at rupture. With these joint additions peak 100-hour rupture values occurred at progressively lower titanium contents as the boron was increased. Maximum rupture strengths of steels containing titanium and/or boron were in most cases much improved by raising the temperature of solution treatment.

Such gain in strength was usually accompanied by a fall in ductility at rupture; this was not, however, so pronounced in the boron-containing steels as in those in which titanium was present. In the titanium-bearing steels peak 100-hour rupture strengths occurred at progressively lower titanium: carbon ratios as the carbon content was increased. In the presence of titanium or boron, additions of zirconium, vanadium, or high nitrogen did not raise the 1500°F. (815°C.) rupture strength of either type of steel.

Hot-rolling characteristics of the titanium-bearing steels studied were uniformly good, but the steels which contained more than 0·40 per cent. of boron at the 0·15 per cent. carbon level were extremely difficult to work; saw-tooth edges developed during rolling.

The properties obtained in the best steels of the respective series are shown in the table below:—

Composition of Steel giving Maximum Strength in the Series		100-Hour Rupture Stress at 1500°F. (815°C.)		100-Hour Ductility at 1500°F. (815°C.)	Solution-Treatment Temperature	
%		p.s.i.	t.s.i.	%	°F.	°C.
Chromium 18, *Nickel* 9, *per cent. series*						
C	0·15	7,100	3·2	5·0	2100	1148
C Ti	0·15 0·75	14,800	6·6	9·0	2300	1260
C B	0·15 0·52	10,000	4·5	16·0	2100	1148
C Ti B	0·15 0·16 0·50	11,800	5·25	14·0	2100	1148
C V	0·15 1·24	10,800	4·8	10·0	2100	1148
C Zr	0·07 0·20	8,600	3·8	15·0	2100	1148
Chromium 17, *Nickel* 12, *Molybdenum* 2·5, *per cent. series*						
C	0·30	9,000	4·0	2·0	2100	1148
C Ti	0·15 0·81	18,500	8·25	5·0	2300	1260
C B	0·30 0·84	18,000	8·0	16·0	2200	1204
C Ti B	0·15 0·78 0·15	20,600	9·2	2·0	2300	1260
C V	0·15 0·59	11,000	4·9	36·0	2100	1148
C Zr	0·07 0·10	10,000	4·5	21·0	2100	1148

On the basis of these preliminary results, further study will be made of titanium-containing and boron-containing chromium-nickel-molybdenum steel and of a similar type of steel modified by a third alloy element which has still to be chosen. The programme will cover determinations of creep and rupture strengths at 1200°, 1350° and 1500°F. (648°, 732° and 815°C.), hot and cold-working characteristics, room-temperature tensile properties, ageing characteristics, susceptibility to embrittlement, and scaling- and oxidation-resistance.

Transformation and Precipitation Phenomena in Austenitic Steels

E. BAERLECKEN and W. HIRSCH: 'Transformation and Precipitation Phenomena in Austenitic Chromium-Nickel Steels at Elevated Temperatures.' *Stahl und Eisen*, 1955, vol. 75, May 5, pp. 570–9.

Literature relating to the effect of transformation

and precipitation phenomena in austenitic steels, on mechanical and other properties, has been concerned mainly with relatively short-time tests and has not dealt exhaustively with the influence of alloy additions (with the exception of molybdenum and niobium). Transformations in austenitic steels are known to take place very slowly, with resultant delay in establishment of equilibrium conditions, but it is of importance that the properties in the final condition be accurately established, with due evaluation of the influence of variation in the basic composition of the steels and of the presence of individual addition elements. The research reported in this paper is designed to make a further contribution to this aspect.

The steels used were within the following ranges of composition:—

Element	%
Carbon	0·055– 0·29
Silicon	0·21 – 3·2
Manganese	0·25 – 3·0
Aluminium	0 – 0·35
Chromium	15·4 –20·8
Nickel	7·7 –15·8
Molybdenum	0 – 2·9
Nitrogen	0 – 0·22
Niobium	0 – 2·0
Titanium	0 – 1·9
Vanadium	0 – 1·25

Thirty steels were used, in which the elements were employed in varying combinations, and the influence of carbon and of additional elements was evaluated by microstructural investigation, by determinations of magnetic saturation, notch-impact toughness, and hardness, and by study of susceptibility to intercrystalline breakdown, as assessed by the boiling copper-sulphate/sulphuric acid standard test of material subjected to prolonged heating at 650°–800°C. Results of tests on steels selected to demonstrate the influence of carbon, silicon, manganese, molybdenum, titanium, and niobium are individually recorded.

In the unstabilized steels the carbon, which in the quenched condition is in solution in the steel, is precipitated in the range 650°–800°C. as carbides. If the steel is not fully austenitic these carbides result in formation of secondary ferrite, which again disappears on prolonged heating. Heavy precipitation of carbide brings about marked embrittlement.

Manganese, in substantial amounts, in spite of its austenite-stabilizing influence, accentuates the embrittlement, and nitrogen also has an intensifying effect, due to formation of a nitrogen compound.

All alloy elements which tend to narrow the γ-region favour formation of the embrittling (iron-chromium) sigma phase, which is formed much more rapidly from ferrite than from austenite. All the elements which have this effect are not, however, equally potent; the authors find that their potency rises in the following order:—niobium, silicon, vanadium, molybdenum, titanium. In steels containing niobium and titanium other phases are also precipitated (Fe_3Nb_2 and Fe_3Ti), and these also have an embrittling influence.

Irrespective of composition, within the limits studied, steels which had been exposed for long periods within the 650°–800°C. range showed satisfactory resistance to the intercrystalline corrosion, i.e., formation of sigma phase is not accompanied by deterioration of the steel in that particular respect. In many cases resistance was improved by the 650°–800°C. treatment.

Creep-Resisting Steels Used in Steam-Power Plants

See abstract on p. 132.

High-Temperature Properties of Plain and Alloy Cast Irons

See abstract on p. 127.

Butt Welding of Rings for Gas Turbines

'Butt Welding Rings for Gas Turbines.' *Machinery* (*Lond.*), 1955, vol. 86, Apr. 29, pp. 919–24.

With the continued development of aircraft gas turbines an increased demand has arisen for rings of various sections, in corrosion- and heat-resisting materials, for joint flanges and similar annular components. Until recently, the normal method of producing such rings was by machining them from pot castings, a method which involved considerable waste of valuable material. Tyre-rolling methods have also been employed, but there are limitations on the sections which can be thus produced and unless they are basically simple, extensive machining may still be necessary.

Recent development in techniques for the hot-extrusion of stainless steels, heat-resisting alloys and other materials, have, however, made available extruded sections suitable for production, by circling and flash-butt welding, of rings of the type required for many components of aircraft and other engineering structures.

Important developments in this connexion have taken place at the works of the Chesterfield Tube Company and the Reynolds Tube Company, whose practices, in production of welded rings, are described in this article. The material used for the majority of the rings made in these works is a titanium-stabilized 18-8 chromium-nickel stainless steel, and it is with the equipment and technique used for this work that the article is mainly concerned. Design of joints, welding equipment and its operation, methods used for controlling the consistency and quality of weld, and post-weld treatment are among the aspects discussed. Similar methods are being applied to production of rings from other aircraft

materials, including high-nickel-chromium alloy (Nimonic 75) and aluminium alloy to D.T.D. 364 specification.

Welded Stainless Steel Rings for Use in Aircraft

T. A. DICKINSON: 'Stainless Steel Fabrication Saves £350,000.' *Welding and Metal Fabrication*, 1955, vol. 23, May, pp. 166–8.

The article describes an application of inert-gas-shielded arc welding which has effected large savings in production of rings used in forming ends for hot-air ducts employed in aircraft. The rings are made from strip stock of titanium- and niobium-stabilized 18–8 chromium-nickel steels, and vary from 1 to 5¼ in. in diameter. Prior to introduction of welding, the accepted method was to machine the rings from heavy-walled tube stock, in order to maintain the close dimensional tolerances essential. The difficulties associated with production of the rings from tube are reviewed, in comparison with the efficiency of the technique made possible by use of welded-strip rings. The stages involved in forming the duct ends, in cam-action dies, are described and illustrated.

Welding of Steels and Alloys for Pressure Vessels

J. J. VAGI, V. R. THOMPSON and D. C. MARTIN: 'Welding of High-Strength Stainless Steels for Pressure Vessels.' *Battelle Memorial Inst., Report B.M.I.* 911, May 5, 1954; 49 pp.

The aim of the research reported was determination of welding conditions suitable for use on materials to be employed in pressure vessels operating at high pressures at 800°F. (426°C.). The primary material and design requirements were:—

(*a*) Over 100,000 p.s.i. (44·5 t.s.i.) weld strength at 800°F. (426°C.).
(*b*) Over 100,000 p.s.i. (44·5 t.s.i.) strength to rupture in 1,000 hours at 800°F. (426°C.).
(*c*) 15 per cent. elongation at 800°F. (426°C.) in short-time tensile tests.

Preliminary survey of high-strength materials likely to meet this specification led to selection, for welding tests, of the following materials:—

These materials were representative of the following types:—

Modified chromium martensitic steel (S.A.E./A.M.S. 5616).
Precipitation-hardening austenitic steels of varying types (S.A.E./A.M.S. 5643, 5528 and 5735).
High-strength high-temperature precipitation-hardening nickel-base alloy (Inconel 'X').
Duplex material comprising low-alloy steel 17-22A(S), clad on one side with austenitic niobium-stabilized steel, Type 347.

The inert-gas-shielded tungsten arc process was used for all the welding tests; joint design was selected in relation to welds likely to be required in pressure-vessel assembly. Test procedures, quality of welds produced, and structures are reported in detail.

The results show that the 5643 and 5528 precipitation-hardening steels, Inconel 'X' and the martensitic steel 5616 can be welded under conditions of high restraint, using the inert-gas-shielded tungsten-arc process. By using post-welding heat-treatments, yield strengths of 100,000 p.s.i. (44·5 tons per sq. in.) or above were obtained in welds in the 5616, 5643 and 5528 steels. In order to secure reasonable elongation it was found necessary to anneal (within the range 1700°–1900°F.: 926°–1038°C.) as part of the post-welding treatment.

The 5735 steel proved to be highly sensitive to hot cracking, and X-ray diffraction and metallographic studies showed the presence of a low-melting-point grain-boundary film.

The tests on Inconel 'X' and the 5528 steel, on the clad material and on the niobium-stabilized 347 steel were less extensive than those made on the other materials, but the preliminary work on Inconel 'X' and the 5528 steel was promising.

Spray-Metallized Coatings: Technique and Applications

S. TOUR: 'Fused-in-Place Spray-Metallized Coatings.' *Welding Jnl.*, 1955, vol. 34, Apr., pp. 329–36.

This review deals essentially with the non-self-fluxing variety of metallic coatings, fused-in-place,

Designation of Material or Specification No.	C %	Cr %	Ni %	Cu %	Al %	Mn %	Mo %	Si %	Fe %	Other Elements %
A.M.S. 5616	0·15	13·00	2·00	0·5 max.	0·15 max.	0·50 max.	0·5 max.	0·5 max.	bal.	Sn 0·05 max. W 3·00
A.M.S. 5643	0·04	16·50	3·75	3·75	—	—	—	—	bal.	—
A.M.S. 5528	0·07	17·00	7·00	—	1·10	—	—	—	bal.	—
A.M.S. 5735	0·045	15·52	26·06	—	0·20	1·35	1·25	0·95	bal.	V 0·32 Ti 1·95
Inconel 'X'	0·08 max.	15·00	72·5	—	0·07	0·65	—	—	5·00–9·00	Ti 2·50 Nb 1·00
Timken 17–22 A(S)	0·30	1·25	—	—	—	0·55	0·50	0·65	bal.	V 0·25
Type 347 Stainless Steel	0·10 max.	17·00–20·00	8·00–12·00	—	—	—	—	—	bal.	Nb (10 × C)

as distinct from the self-fluxing hard and corrosion-resistant alloy coatings of the nickel-chromium-boron-silicon type. The nature of self-fluxing alloys and the general principles involved in using them as coatings are first considered, and a condensed account is given of the development of the concept of fusing-in-place of sprayed metal coatings, from the early days of the Schoop gun to the present time.

The advantages of this form of coating are then discussed, e.g., the high degree of adhesion resulting from alloying of the coating with the basis metal; elimination of the inherent porosity of sprayed metal and the resulting complete sealing-off of the base metal from the surrounding environment; the possibility of spraying alternate or composite layers of different metals, of varying thickness, to build up a coating of the desired final composition.

The major portion of the paper is concerned with well illustrated descriptions of typical fused-in-place coatings; structures as sprayed and after fusing are shown in a series of photomicrographs. Among the types of coating to which reference is made are the composite varieties:—

Nickel-chromium-boron-silicon/nickel-molybdenum iron
Nickel-chromium-boron-silicon/Monel
Aluminium and nickel-chromium/aluminium
Monel/aluminium
Stainless steel/aluminium
Nickel/zinc
Nickel/tin.

It is urged that the possible applications of fused-in-place composite coatings are only just being realized: the potential value of the method is being increasingly recognized, but considerable development work remains to be done.

Electrochemical Study of Intercrystalline Corrosion in Austenitic Steels

E. BRAUNS and G. PIER: 'Study of Intercrystalline Corrosion in Austenitic Chromium-Nickel Steel.' *Stahl und Eisen*, 1955, vol. 75, May 5, pp. 579–86; disc. p. 586.

The authors urge the advantages of electrochemical technique in investigation of the corrosion-resisting characteristics of stainless steels, and describe experiments designed to elucidate the mechanism of intercrystalline breakdown of austenitic steels after heating in the 650°C. region. The material used was an unstabilized steel containing carbon 0·08, chromium 8, nickel 7·6, per cent. which, after quenching, was re-heated for 192 hours at 650°C. Current-potential curves were obtained on the steel, in the quenched and in the sensitized conditions, and the course and character of these curves were correlated with the mechanism of attack in the standard copper-sulphate/sulphuric-acid solution. Comment is made on the occurrence of two activation potentials: the grain boundaries were found to be activated at a higher potential than the grain-surface material. The experiments made with the copper-sulphate solution indicated that its effectiveness in producing intercrystalline breakdown is closely related to the redox potential: the more rapidly this potential establishes itself at values within a critical potential range, the more potent is the action of the solution. Factors affecting the adjustment of the redox potential were investigated: the presence of foreign ions and the oxygen content of the solution were found to be significant. The occurrence of chromium depletion at the crystal boundaries and in the region immediately adjacent to them was confirmed by chemical analysis.

Titanium in Iron and Steel: Textbook

See abstract on p. 131.

Condenser-Tube Alloys: Factors Affecting Selection

H. A. TODHUNTER: 'Material Selection for Condenser Tubes.' *Corrosion*, 1955, vol. 11, May, pp. 221t–4t.

The background of the views expressed in this paper is experience gained in operation of the Harbor Steam Plant of the City of Los Angeles over a prolonged period, supported by data available from other sources. It is shown that in selecting tube material for sea-water condensers two main factors must be considered; first, the water conditions, and second the design features of the cooling-water system which may influence performance and/or life of the tubes. In the analysis of behaviour of various materials which is given in this paper, the effect of the velocity of the cooling water in the tubes is shown to be an important factor: the author presents a study of the costs of the entire cooling-water system in relation to varying velocities.

A detailed account is given of the polluted water conditions in which the tubes of the Harbor Steam Plant are forced to work. The effects of anaerobic bacteria were accelerated by sulphur compounds secreted by the bacteria, and at the worst stage aluminium-brass surface condenser tubes were failing after about one year's service.

A review is made of the methods adopted for elimination of hydrogen sulphide and bacteria from the water, and of other means used to extend tube life, and a detailed account is given of an economic study and tube tests made to determine the type of tubing best suited for use in the particular conditions obtaining at the Harbor Steam Plant. As a result of this research, it was decided to use 70–30 cupro-nickel tubing and it is considered likely that in future installations in this region the same type of tube will be employed, combined with attention to optimum quantity and velocity of cooling water.

In an appendix to the paper the author makes an illustrated report on tests of 1,500 tube specimens installed in a 6,000 sq. ft. twin-shell sea-water condensing unit, receiving cooling water from Los Angeles inner harbour. The specimens were removed at intervals during the past few years. The condition of aluminium brass, aluminium bronze and 70–30 (iron-containing) cupro-nickel, after 5,000, 15,000 and 50,000 hours of service is shown. The cupro-nickel containing ½ per cent. of iron gave consistently the best performance. (It is noted that Admiralty metal

tubes were also initially included in the test, but that the rate of failure after about one year was so excessive that they were removed from the condenser. No detailed report is made on them.)

Salt-Spray/Acetic-Acid Corrosion Test for Plated Parts

'Salt Spray Passes Acid Test.' *Steel*, 1955, vol.136, May 9, pp. 92, 94.

This brief article gives evidence of the validity of the acetic-acid-modified salt-spray test which has recently been under examination by the American Society for Testing Materials, as an improvement on the standard sodium-chloride spray test covered by A.S.T.M. B.117, the value of which is widely questioned.

Tests in the acetic-acid-containing salt spray have given results closely agreeing with the behaviour of given coatings of many types in atmospheric conditions, and the Society has now recommended adoption of the modified method as a Tentative Standard.

Effect of Low Temperatures on Brittleness in Metallic Materials

See abstract on p. 128.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks*.

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